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Distribution of Intelligence in Airborne Air-Defense Mission Systems

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Summary

This paper addresses the distribution of intelligence, knowledge and learning capability among the main system elements. The enabling technologies are briefly introduced and the overall and subsystem structures are presented. In this context functional intelligence is integrated into the weapon system (air-air missile) yielding a considerable level of autonomy. This is complemented by a missile mission unit as part of the mission avionics which intelligently supports the pilot taking into account the new capabilities of the weapon system. Altogether this leads to improved efficiency and efficacy as well as extended functionalities of the air defense system.

The system evolves with the learning capabilities of the intelligent elements starting with initial knowledge and by learning from experience, thus improving automatically. To gain experience in a variety of situations, applications and missions, training can be performed applying advanced embedded simulation and including virtual reality. Of course, also ACMI-type training is possible utilizing new range independent air combat training and debriefing systems.

1 INTRODUCTION

Tactical Systems are implemented as Integrated Mission Systems (IMS) such as air- and space defence systems. Key elements of IMS are platforms with sensors and effectors, ground-based components with communication, command and control etc.

Airborne Air Defense represents a very difficult mission because

- it is so dynamic,
- it depends so heavily on situational awareness, pilot skill and quick decisions,
- multiple sensor information must be tracked,
- communication/IFF must be performed,
- of close proximity to adversary AC and highly dynamic geometry.

Optimization of an intelligent mission system design can only be realised if a common approach is taken to the interpretation, implementation and integration of the weapon system, avionics and cockpit functions, as they are depicted in the very simplified blockdiagram of Fig. 1.

Paper presented at the RTO SCI Symposium on "System Concepts for Integrated Air Defense of Multinational Mobile Crisis Reaction Forces", held in Valencia, Spain, 22-24 May 2000, and published in RTO MP-063.

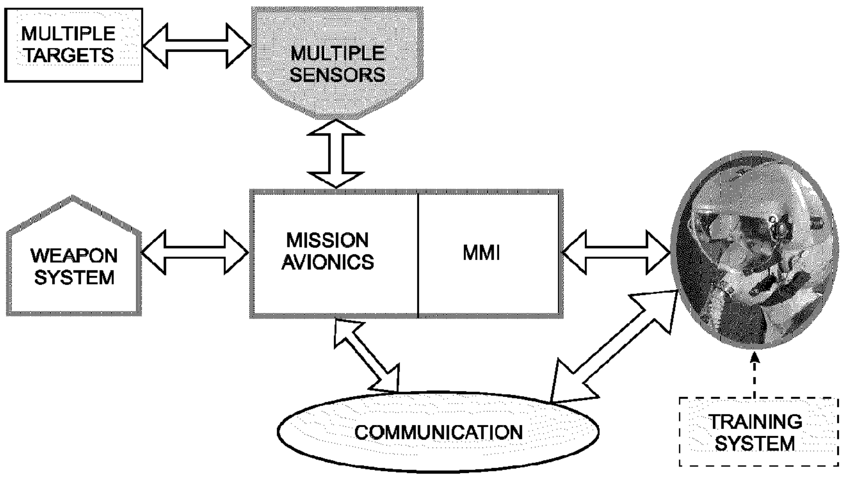

Figure 1: Air defense system block diagram

A structured approach is therefore required to the design of an advanced integrated airborne air-defense mission system that considers the mission avionics hardware, software and human pilot together with the air to air missile weapon system. This is vital if we are to obtain required enhanced mission system performance whilst reducing the overall aircrew workload and simultaneously staying within affordable cost margins.

Structured system design methods and mission and task analysis must therefore be a cohesive part of the corresponding integrated mission system. The design must be based on optimum functional and technical partitioning of the elements

- weapon system
- mission avionics
- man-machine interface
- pilot

2 THE IMPACT OF COMPUTATIONAL AND MACHINE INTELLIGENCE

The development, procurement and utilization of defense system will in future be strongly influenced by the affordability issue as already mentioned before. A considerable potential for future cost reduction is seen in the extended use of artificially intelligent autonomous elements as part of the IMS. Moreover, driven by ever increasing requirements there is a demand for extended and improved decentralized intelligence and autonomy concerning airborne air defense systems. The key notion of "autonomy" is intimately connected with advances in information technology. In this context the following question arises immediately: What is computational, machine or more generally artificial intelligence? In relation to the issues and topics treated here, the following answer shall be given.

- Systems/units have no artificial intelligence if a program/software "injects" them with what they have to do and how they have to react to certain pre-specified situations.
- Systems/units have artificial intelligence if their „creator" has given them a structure - not only a program - allowing them to organize themselves, to learn and to adapt themselves to changing situations.

Thus intelligent structures must be able to comprehend, learn and reason.

The automation of intelligent functions does require methods, techniques, technologies by means of which

- the cognitive abilities of humans for detection, classification, identification, assessment of a situation and of objects in it as well as for goal-oriented behavior can be automated (see Fig. 2).
- a complex problem-solving knowledge (algorithmic, heuristic) for real-time processing can be mapped on (nonlinear) network structures.
- the reflexive and knowledge-based behavior of humans (e.g. perception eye/ear) can be modelled and thus included in an optimum design of the man/machine interface.
- training and instruction systems can be implemented which take into account the specific learnability of the elements of the mission system such that an optimum distribution of intelligence is ensured.

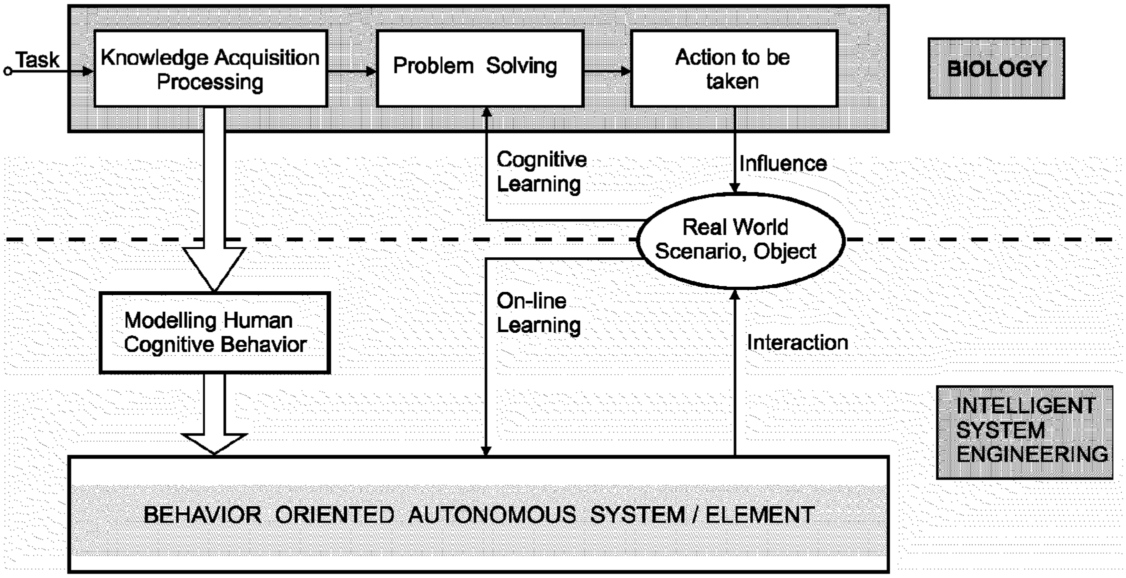

Figure 2: Modeling human cognitive behavior

There is a paradigmatic complementary shift from conventional artificial intelligence, knowledge based (AI/KB) techniques to new so called soft computing technologies, which are based on modelling the conscious, unconscious, cognitive reflexive functions of the biological brain. In contrast to the conventional method, soft computing [1] addresses the pervasive imprecision of the real world. This is obtained by consideration of the tolerances for imprecision, uncertainty and partial truth to achieve tractable, robust and affordable cost solutions for complex problems.

Important related computing methodologies and technologies include among others fuzzy logic, neuro-computing, as well as evolutionary and genetic algorithms which are described very briefly as follows.

- **Neural networks** are derived from the idea of imitating brain cells in silicon and interconnecting them to form networks with self-organization capability. They are modelled on the structures of the unconscious mind.
- By contrast, **fuzzy logic/fuzzy control** has developed an exact mathematical theory for representing and processing fuzzy terms, data and facts which are relevant in our conscious thinking.

- **Genetic algorithms** are based on the mechanism of natural selection and genetic evolution which offer search, optimization and learning behavior.
- A **combination of these techniques** as indicated in Fig. 3 is of particular importance for achieving unprecedented levels of self-organization capability and learnability and thus a new kind of artificial, computational and machine intelligence (CMI) in technical equipment and systems.

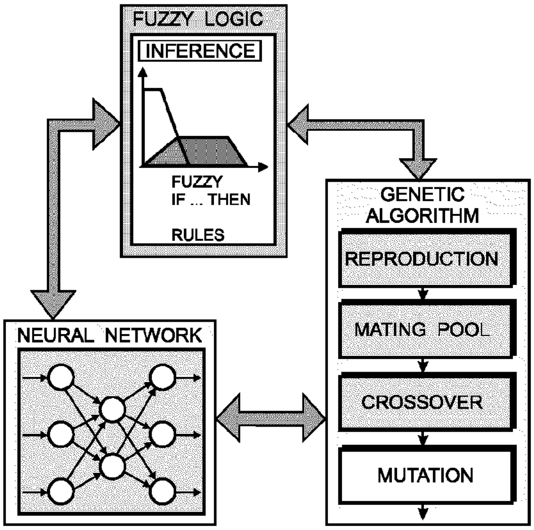

Figure 3: Soft computing techniques

Together with conventional algorithmic processing, classical expert systems, probabilistic reasoning techniques and evolving chaos-theoretic approaches the techniques treated here enable the implementation of knowledge based functions. Genetic and evolutionary algorithms can be applied to generate and optimize appropriate structures and/or parameters to acquire, encode, represent, store, process and recall knowledge. This yields self-learning control structures for dynamic environments that evolve, learn from experience and improve automatically in uncertain situations. Ideally, they can be mechanized by a synergetic complementary integration of fuzzy, neuro and genetic techniques (Fig. 3). Fuzzy logic for decision making and reasoning, neural networks for learning and self-organization and genetic algorithms primarily for task oriented optimization. These soft-computing techniques support the move towards adaptive knowledge based system or system elements which can rely on experience rather than on the ability of experts to describe the dynamic, uncertain world perfectly in order to program (top-down) the system or corresponding element for a predetermined behavior. Thus, soft computing techniques in conjunction with appropriate system architechtures provide the basis for creating behavior oriented systems or elements with appropriately distributed intelligence (Fig. 2). In the following, this will be looked at with respect to an air defense system.

3 SYSTEM-WIDE DISTRIBUTION OF KNOWLEDGE AND INTELLIGENCE

3.1 General remarks

The combined effects of new information technology and telecommunication are leading to whole new developments and IMS structures [2]. While progress made in information technology enables us to cope with tasks which are becoming increasingly complex, telecommunication is eliminating the dependence on distance and time as far as advanced mission management processes are concerned and as highlighted by the following issues:

- Enable full spectrum decision aiding/ automation network ranging from the C^3 environment down to the vehicle on board system level, to allow unprecedented degree of autonomy and decentralized freedom of action, using common consistent decision frame-work/criteria.
- Broad continuous information available to all operational levels together with suggested plans of action and proposals for optimum implementations, produced by machine intelligence, to provide dramatically improved situation awareness which in turn can improve both effectiveness and efficiency of force application.
- Enable distributed, flexible command structures designed by force commander to optimize response and action for any mission, operation or situation.

Related trends can indeed be called revolutionary and there is hardly any other example which confirms the quotation of Le Corbusier more forcefully: "One does not stage a revolution by rebelling, but by delivering the solution!"

In this context and looking at the title of this paper the following question arises immediately: How do we - in a first careful step - distribute knowledge and intelligence among the main elements weapon system, mission avionics, man-machine interface, considering the "given" cognitive capabilities of the pilot, however, also accounting for the human deficiencies and limitations in more demanding scenarios and in the operation of complex, highly integrated systems.

3.2 Weapon system

In order to

- improve the performance (firing zones)
- increase the availability
- reduce the cost of aircraft-missile integration
- increase the autonomy

it is highly recommended, if not to say mandatory, to integrate functional intelligence into the future air-air missile.

Consequently Bodenseewerk started some years ago R.a.D. work to apply neuro, fuzzy, and neuro-fuzzy network techniques for knowledge-based learning guidance and control. A functional blockdiagramm is shown in Fig. 4. The function of the missile guidance and control loop is to determine appropriate controls to produce a flight path such that the mission objective is achieved in the most efficient manner.

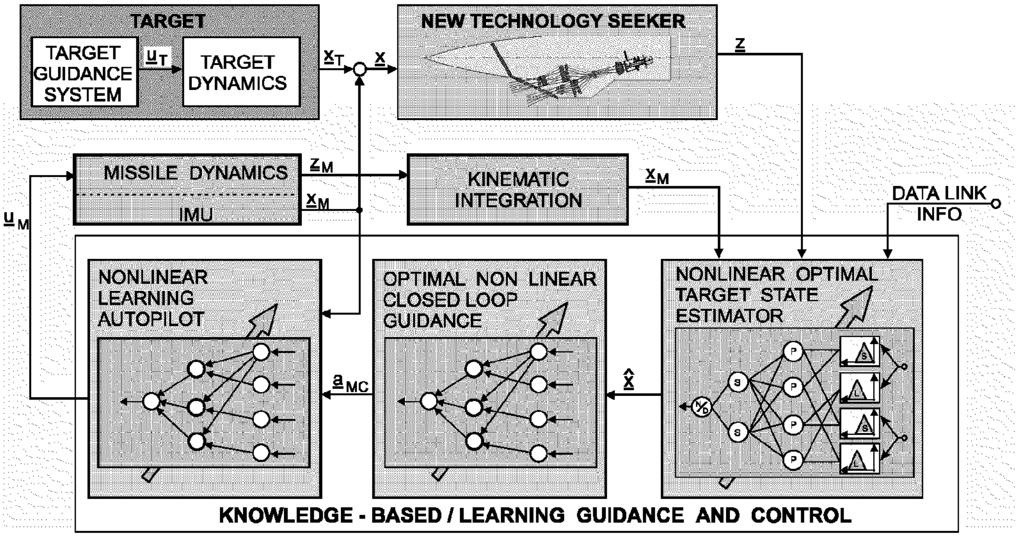

Figure 4: Functional block diagram of the guidance and control loop

Together with an all solid state new technology seeker, where also neuro-fuzzy techniques are applied for sensor processing [3], the knowledge-based learning guidance and control approach provides the following attributes:

- Application of most advanced guidance and control techniques
  - superior guidance and control performance
  - high agility
  - extended flight envelope
  - large operational ranges
  - increased pilot survivability by intercepting near hemishere targets
- Implementation as parallel networks
  - fast computation, high bandwidth
  - inherent redundancy, fault tolerance
- Providing learning, health monitoring, self-repair capability
  - high reliability and mission success probability
  - increased availability
  - compensation of design uncertainties
  - improved cost effectiveness

Altogether this leads to improved efficiency and efficacy as well as extended functionalities. In this context some aspects of the paramount potential of the missile´s learning capability such as the acquisition of expert knowledge and (sub)-systems behavioral knowledge as well as the acquisition of operational knowledge from experienced pilots and last but not least the continued knowledge acquisition during real mission are to be mentioned here.

3.3 Mission Avionics

The general objective is to support new kinds of capabilities (knowledge processing, learnability) of future missiles by a complementary module on the aircraft side in the mission avionics, thus further increasing the functionality and effectiveness of the missiles and their utilization, which leads to a decisive improvement of their performance and availability.

The extended functionality allows the pilot's workload to be reduced through introduction of a Missile Mission Unit (MMU) as pilot support element, thus achieving a decisive reduction of the time constants in the so-called "recognize-act-cycle" of the missile utilization.

The "recognize-act-cycle" comprises functions for sensor fusion, situation assessment and awareness, reasoning and decision making as well as fire control, trajectory generation and weapon release.

For future support systems a degree of artificial intelligence is required, such that in the expected highly dynamic scenario a considerable portion of these functions can be removed from the pilots workload. Fig. 5 shows the structure of the recognize act cycle with the air-to-air scenario, the aircraft and missile sensors for situation measurements, the MMU with dedicated functions and last but not least with the pilot in the loop as final decision element regarding the goal directed interactions with the real scenario.

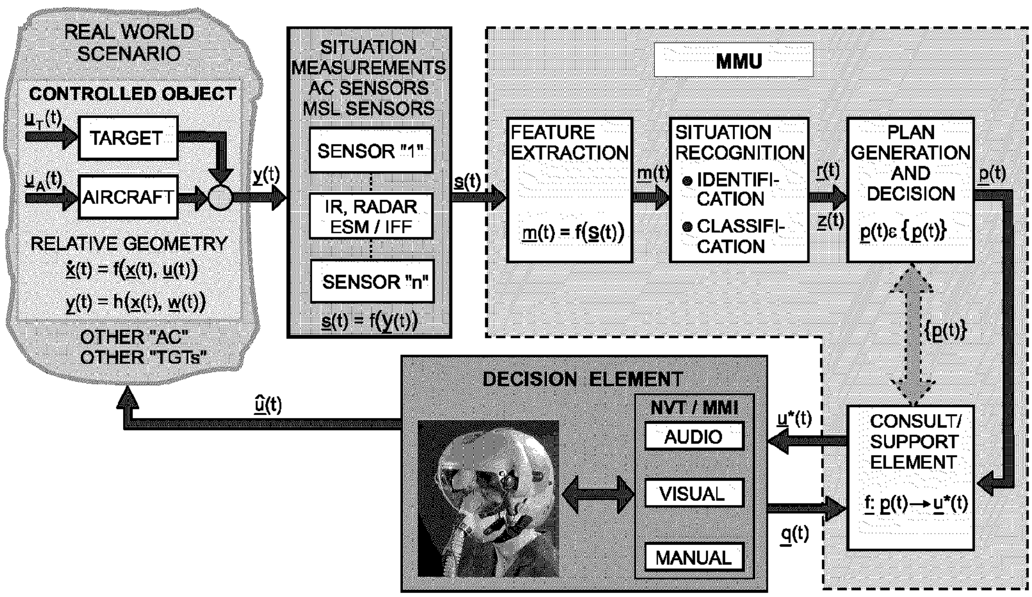

Figure 5: Recognize-act-cycle structure with MMU functions

The functions performed by the MMU are summarized in Fig. 6, which also shows in a much simplified way the integration of the MMU with the aircraft and missiles.

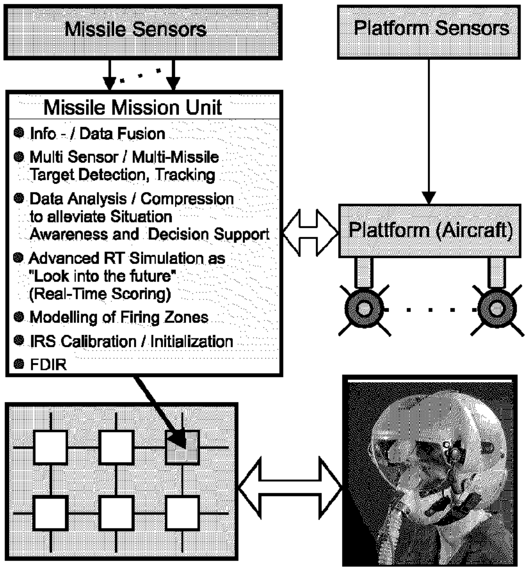

Figure 6: MMU function and integration with the aircraft and missile

Applying CMI techniques as introduced in chapter 2 and implemented in hardware and/or software, the MMU will be integrated into a future modular avionics computational network structure. This way of distributed processing in networks with standard interfaces (photonic in future) supports and complements the concept of distributed intelligence with cooperative behavior.

Finally, it is worth mentioning, that the neuro-fuzzy failure detection, identification and reconfiguration function greatly enhances the availability of the missile system.

3.4 Man-Machine Interaction

This is a very specific subject and shall be covered here only by a few remarks. CMI tools, implemented in intelligent machines or system modules will help the human brain to have better ideas, generate better solutions and respond faster in complex dynamic situations.

Life science research will discover new ways to move forward the limits of human mental and related physical capabilities and to model the human brain by brainlike structures implemented in technical constructs, for the interaction of the human with intelligent machines, applying new visualisation techniques (NVT) such as e.g. virtual interface technology [4].

The useware needed for this interaction is of ever increasing importance. Under the notion useware all software and hardware components serving the use of a complex technical system are accomodated.

There is a need for human centered control concepts, which is a challenge for both engineers and cognitive scientists. Within this context work is required in two main areas:

- Direct interfacial mechanisms to improve modes of interaction, e.g. speech.
- Overall system design to make the system/machine more like a human, i.e. accepting high level instructions and understanding operators needs and intentions.

Intelligent useware should give the human operator so much control as he or she wants and can use, and intelligently fill in the remaining required functions. Software/hard-ware that can think and learn will be part of it to e.g. analyse the behavior of the operator and account for it when generating recom-mended interactions.

4 CONCLUSIONS

The concepts described in this paper represent a step towards distributed intelligence with cooperative behavior in airborne air defense systems requiring enabling technologies and techniques available today. A more future oriented approach based on a so called holonic system with subsumption (behavioristic) architecture is dealt with in [2].

The knowledge-based intelligent subsystems or modules as treated here offer learning capability. They are not only programmed in the conventional way. Starting from initial knowledge the CMI elements evolve by learning from experience and thus improving automatically. Like practice in engineering it is an indispensable prerequisite, that systems with the said new functionalities and features as described here must be designed, built, trained and utilized according to an adapted dedicated new strict methodical approach.

Based on a suitable training (learning) strategy the system acquires some of its knowledge during a training phase. Training can be performed applying simulation including virtual reality. Within this context environments can be used that are much more changeable than the real ones. Fig. 7 depicts the use of embedded simulation [4] to support a variety of applications as well as situations and incorporating both real and simulated mission (weapon) systems, which are linked together by communication to conduct combat exercises and training.

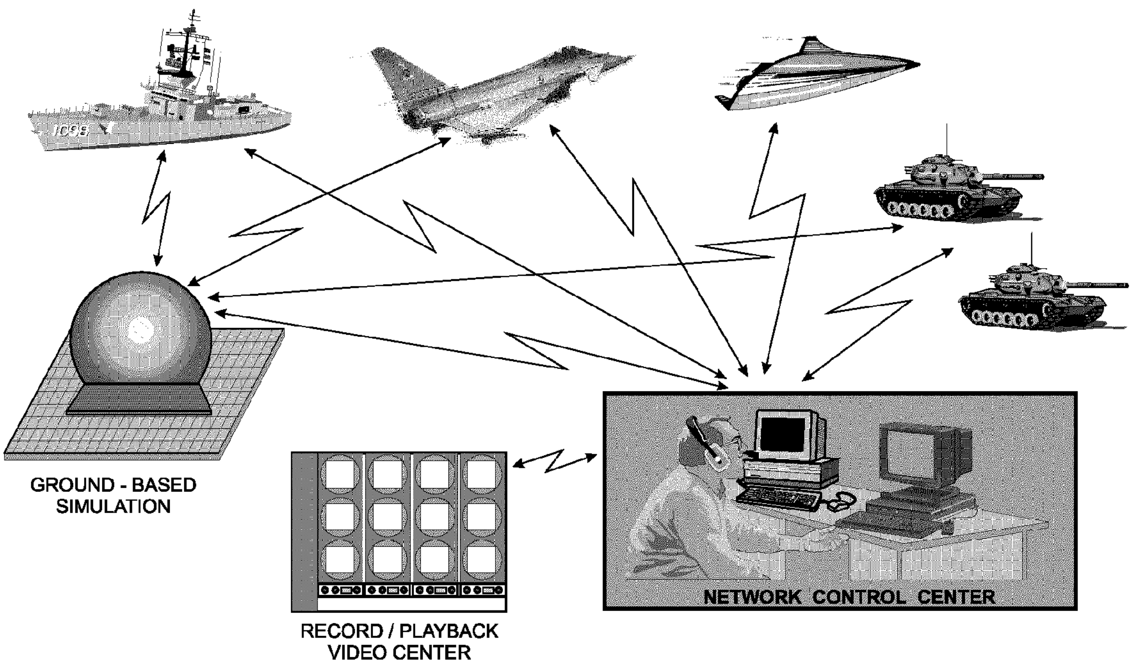

Figure 7: Embedded simulation for training and exercise

Of course, also ACMI type training is possible utilizing new range-independent air combat training and debriefing systems, such as described in [5].

After completion of training the behavior is assessed with respect to correctness (required behavior), robustness (behavior vis-à-vis changing environment) and adaptiveness. Based on this assessment, further iterations during the engineering steps might become necessary in order to make the satisfactorily behaving system evolve from them on a step by step basis.

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